Low-Friction Coatings and Materials for Fuel Cell Air Compressors

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Objectives

Develop and evaluate the friction and wear performance of low-friction coatings and materials for fuel cell air compressor/expander systems. Specific goals are:

- 50 to 75% reduction in friction coefficient
- One-order-of-magnitude reduction in wear
- Transfer of the developed technology to DOE industrial partners

Technical Barriers

This project addresses the following technical barriers from the Fuel Cells section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year R,D&D Plan:

- A. Compressors/Expanders

Approach

- Identify critical compressor components requiring low friction.
- Apply Argonne's near-frictionless carbon (NFC) coatings to the components where appropriate and evaluate.
- Develop polymer composite materials containing boric acid solid lubricant and evaluate.
- Develop tribological mechanism-based material selection methodology for various compressor/ expander components.

Accomplishments

- Identified the radial air bearings and thrust bearings of Meruit's turbocompressor as components that require both low friction and low wear rate for satisfactory performance.
- Thrust washer wear tests showed that Argonne's NFC coating reduced friction by about four times and wear rate by two orders of magnitude. Both exceeded the project goals.
- NFC coatings increased the scuffing resistance of a steel surface about 10 times.
- NFC-coated air bearing hardware components are currently undergoing durability testing.
- Completed initial friction and wear testing of Nylon-12 polymer with B_2O_3 addition. Significant reduction in wear was observed with the addition of B_2O_3, especially under high relative humidity.
- Achieved 50% reduction in friction for application in Variex-variable displacement compressor/ expander using Hitco C/C composite and anodized Al contact pairs.
- Designed and constructed a new high-speed friction and wear test rig for evaluating materials for Mechanology's torroidal intersecting vane machine (TIVM).

- Evaluated high-speed frictional performance of several candidate materials and coatings for TIVM vanes.

Future Directions

- Develop a tribology-based material selection methodology for compressor and blower components.
- Compile a database of pertinent candidate material and coating properties.
- Conduct a detailed tribological performance evaluation of TIVM select candidate materials based on high-speed frictional behavior.
- Optimize NFC coating for TIVM vane application.
- Coat TIVM components with optimized NFC for rig testing at Mechanology.
- Initiate efforts to address tribological issues in AD Little and UTC Fuel Cells, Inc. compressor/expander programs.

Introduction

A critical need in fuel cell systems for vehicles is an efficient, compact, and cost-effective air management system to pressurize the fuel cell systems to about 3 atmospheres. Pressurization of fuel cells will result in higher power density and lower cost. Because no off-the-shelf compressor technologies are available to meet the stringent requirements of fuel cell air management, several compressor and blower systems are currently being developed for DOE by different contractors. The efficiency, reliability and durability of compressors depend on effective lubrication or friction and wear reduction in critical components such as bearings and seals. Conventional oil or grease lubrication of compressor components is not desirable because such lubricants can contaminate and poison the fuel cell stack. The objective of this project is to develop and evaluate low-friction coatings and/or materials for critical components of air compressor/expanders being developed by various contractors for DOE vehicular fuel cell systems. The work this year focused on evaluation of materials and coatings for Mechanology's TIVM, as well as the development of generalized material selection methodology for compressor components.

Approach

For various air compressor/expanders being developed, we will identify the key critical components that require low friction coefficient and wear resistance. Over the years, the tribology group at Argonne has developed low-friction and low-wear coatings and materials. Most notable is the discovery of an amorphous carbon coating with extremely low friction coefficients (<0.001 in dry nitrogen) and very low wear. Where appropriate, the NFC coating will be applied to the critical component(s). Other commercially available low-friction coatings will be evaluated for various applications. In some cases, alternative low-friction polymeric materials and other low-friction coatings will be evaluated.

Results

Mechanology TIVM. The primary sources of friction in the TIVM are the vane sliding interface, the housing compressor seal and expander bearings. Design analysis shows that overall system friction coefficient less than 0.3 is required to meet the DOE program target for efficiency. The most critical of the three TIVM friction sources is the vane sliding interface because of its high sliding speed of 60-75 m/s. Selection of appropriate vane material is critical for successful operation of the TIVM compressor/expander. As reported last year, preliminary frictional behavior as a function of sliding speed was evaluated for several material and coating (including NFC) combinations. Some material combinations with adequate friction behavior at high sliding speeds were identified.

More detailed tribological evaluations were conducted for potential TIVM vane materials. The three-ball-on-disc high speed test rig was refurbished to make it more robust. The normal and tangential forces are now measured by a three-axes load cell (Figure 1). This will allow more accurate measurement of friction coefficient as the variation in the normal force is taken into account. The test rig is also now equipped with an environmental coated chamber, allowing the variation of relative humidity. Friction and wear tests were conducted as a function of sliding speed for candidate vane materials and coatings at ambient room relative humidity (~30% RH) and at 100% relative humidity. Figure 2 shows the variation of the friction coefficient with sliding speed for various materials and coatings meeting the friction requirement of 0.3 under ambient room air. The lowest friction coefficient was obtained when both the disc and the ball surfaces were coated with NFC. Steel on polyetheretherketone (PEEK) shows

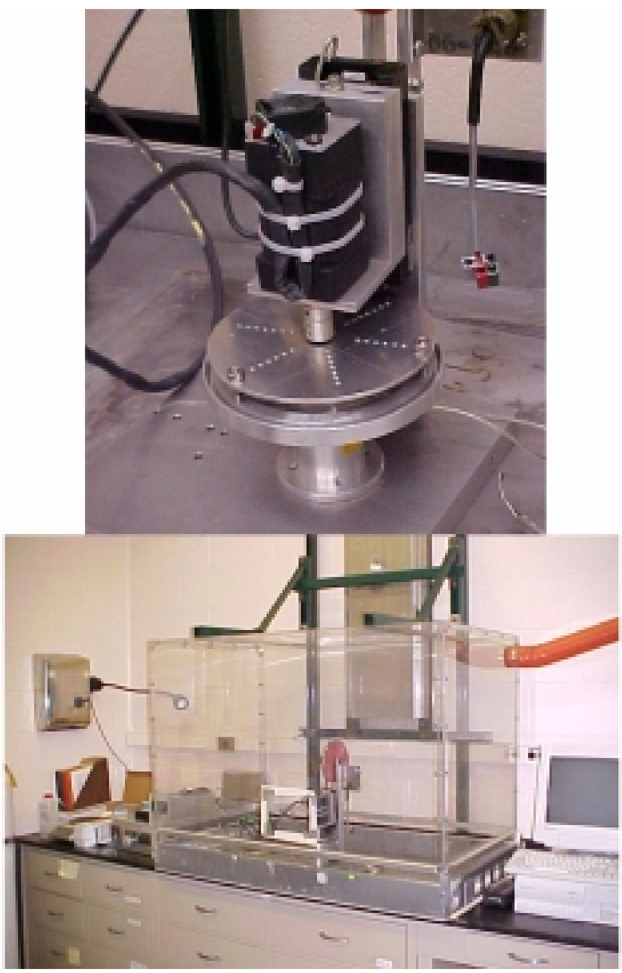

Figure 1. Picture of Modified High Speed Friction and Wear Test Rig With 3-Axes Load Cell and Environmental Chamber for Humidity Control

friction coefficients less than 0.15 for the speed range evaluated. Under 100% relative humidity, the friction coefficients for all the materials evaluated were lowered (Figure 3). This may be due to hydrodynamic lubrication by the presence of water at the sliding interface. At the very high sliding speed, the friction coefficients for all material pairs were approaching the same value. This is consistent with the possibility of hydrodynamic lubrication by water. Figure 4 shows the wear on balls of various materials sliding on PEEK and NFC-coated discs. Minimal wear was observed on the balls sliding on PEEK, except for brass (Figure 4, top). Due to higher hardness of the NFC coating, it produced more wear on the balls slid against it (Figure 4, bottom).

Conclusions

More detailed friction and wear evaluation of candidate materials and coatings for Mechanology TIVM vanes showed that humid air will not have adverse effects on the friction behavior of these materials, at least for a short duration of time. Long-

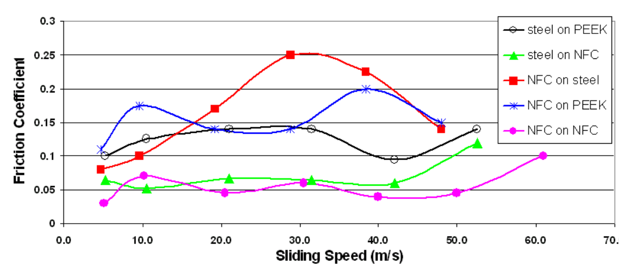

Figure 2. Variation of Friction Coefficient with Sliding Speed for TIVM Vane Candidate Material and Coating Combinations in Ambient Room Air (30% RH)

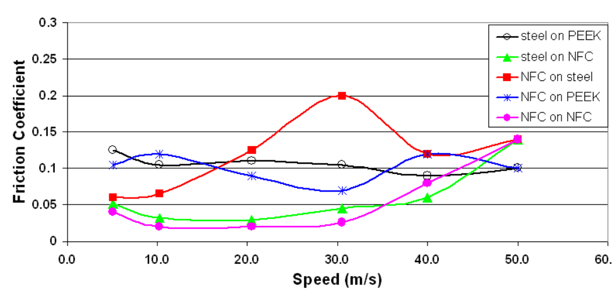

Figure 3. Variation of Friction Coefficient with Sliding Speed for TIVM Vane Candidate Materials and Coatings under 100% Relative Humidity

term effect of humidity must be assessed as part of future efforts.

A

B

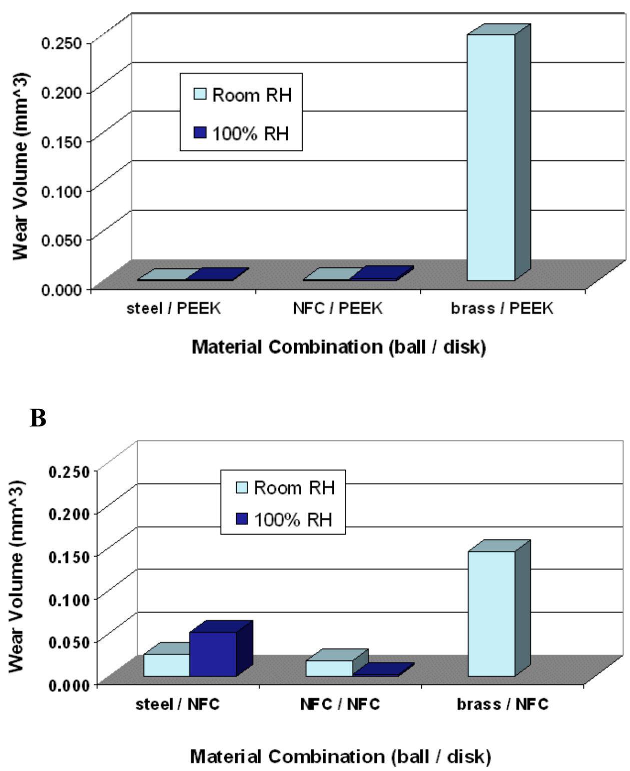

Figure 4. Wear Volume in Various Balls Slid Against (top) PEEK Disc and (bottom) NFC-Coated Steel Disc

FY 2003 Publications/Presentations

1. O. O. Ajayi, A. Erdemir, and G. R. Fenske, "Low Friction Coatings and Materials for Fuel Cell Compressor & Blowers," 2003 Merit Review and Peer Evaluation Meeting, May 19-22, 2003. Berkeley, California.